REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	20 Oct 95	

4. TITLE AND SUBTITLE The Effects of Differing Glycemic Index Meals on Substrate Utilization and Endurance Performance

5. FUNDING NUMBERS

6. AUTHOR(S)

Steve E. Black

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

AFIT Students Attending:

~~Steven E. Black~~ Colorado State University

8. PERFORMING ORGANIZATION REPORT NUMBER

95-118

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

DEPARTMENT OF THE AIR FORCE
AFIT/CI
2950 P STREET, BLDG 125
WRIGHT-PATTERSON AFB OH 45433-7765

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for Public Release IAW AFR 190-1
Distribution Unlimited
BRIAN D. Gauthier, MSgt, USAF
Chief Administration

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

19951031 117

14. SUBJECT TERMS	15. NUMBER OF PAGES 38
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT

THESIS

THE EFFECTS OF DIFFERING GLYCEMIC INDEX MEALS ON SUBSTRATE UTILIZATION AND ENDURANCE PERFORMANCE

Submitted by

Steven E. Black

Department of Food Science and Human Nutrition

In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer 1995

COLORADO STATE UNIVERSITY

March 30, 1995

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY STEVEN E. BLACK ENTITLED THE EFFECTS OF DIFFERING GLYCEMIC INDEX MEALS ON SUBSTRATE UTILIZATION AND ENDURANCE PERFORMANCE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee On Graduate Work

Advisor

Department Head

ABSTRACT OF THESIS

THE EFFECTS OF DIFFERING GLYCEMIC INDEX MEALS ON SUBSTRATE UTILIZATION AND ENDURANCE PERFORMANCE

Few studies have investigated the effects of pre-exercise meals with differing glycemic responses on substrate utilization and endurance performance in subsequent exercise. Those few which have been done have looked at foods of limited application to a pre-exercise meal consumed prior to a morning event. This study investigated the effects of commonly eaten breakfast cereals on exercise performance.

Ten physically active male subjects participated in this study. The subjects reported to the performance laboratory in the morning following an overnight fast (10-12 hours). Upon arrival, the subjects were weighed and then fed either a high glycemic index (GI) meal (corn flakes, banana, 1% low-fat milk) or moderate glycemic index meal (oatmeal, banana, 1% low-fat milk) containing 100 grams of carbohydrate (77% carbohydrate). A third trial using a continued fast served as a control. Trials were performed in random order. After consumption of the meal, the subjects remained seated for one hour before beginning a one-hour submaximal cycling trial at 70% $VO_{2\ max}$ followed immediately by a maximal performance test to exhaustion. Blood was sampled pre-meal, pre-exercise, every 15 minutes of exercise and at completion of the performance test and analyzed for plasma glucose, free fatty acids, and lactate. Metabolic measurements collected every 15 minutes of exercise and during the maximal performance test included heart rate (HR), pulmonary ventilation (V_E), oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER). The data were analyzed using a randomized block analysis of variance with repeated measures A one-

way analysis of variance was used to determine differences between mean times to exhaustion. The level of significance was set at $p<.05$.

The results indicate pre-exercise meals with differing glycemic indices significantly altered substrate utilization throughout 60 minutes of submaximal exercise. The fed trials resulted in increased carbohydrate oxidation as evidenced by significantly higher RER values ($p<.001$) than in the fasted trial. The highest RER was observed with the high GI trial followed by the moderate GI trial and then the fast. The high GI meal resulted in lower plasma glucose at the beginning of exercise than the fasted trial ($p=.018$) but there was no significant differences between the two fed trials. The fed trials produced no significant treatment effects on blood glucose and lactate throughout 60 minutes of submaximal exercise. Plasma FFA increased significantly ($p=.037$) from 0-15 minutes with the moderate GI meal while the high GI meal inhibited the rise although no further treatment effects were observed for the remainder of submaximal exercise,. There were no differences in time to exhaustion or on work output at the end of the maximal performance test. Furthermore, there were no significant treatment effects on plasma glucose, lactate, FFA or RER during the performance test. There was no significant treatment effect on VO_2, VCO_2, V_E, or heart rate during either the submaximal trial or the performance test. In sum, the moderate GI meal significantly altered substrate utilization during 60 minutes of submaximal exercise by increasing carbohydrate oxidation above the fasted trial but below the high GI trial. This did not, however, help to significantly increase substrate availability during the exercise period or improve endurance performance.

Steven E. Black
Department of Food Science and Human Nutrition
Colorado State University
Fort Collins, Colorado 80523
Summer, 1995

ACKNOWLEDGMENTS

Heartfelt thanks to my committee members, Dr. Mary Harris, Dr. Loren Cordain, and Dr. Chris Melby, who have each provided unique contributions to this research as well as to my overall graduate education -- thank you for the considerable insight and direction over the past two years. Thanks also to Dr. Dale Devoe for his statistical expertise and Dr. Bob Gotshall for his advice in the lab. I'm grateful to everyone else involved in this study, especially my fellow graduate students, as it would not have been possible without their advice, criticism and assistance. A final note to Carolyn, Sarah and Travis who have, through their support and love, made this a time to remember and cherish.

Table of Contents

Table of Contents (continued)

Chapter **Page**

CHAPTER I

INTRODUCTION

Research over the past twenty years has highlighted the importance of nutrition in improving athletic performance. Particular attention has focused on the role of dietary carbohydrate in energy metabolism during exercise. It is well established that sufficient carbohydrate during training can increase muscle and hepatic stores of glycogen, the primary source of glucose for exercising muscle in exercise of long duration at a moderate intensity (Coggan & Swanson, 1992; Coleman, 1994; Costill & Hargreaves, 1992). The increase in glycogen stores provides the fuel for extended exercise through glycolysis and may delay the onset of hypoglycemia and the many symptoms of "hitting the wall:" severe fatigue, nausea, and extreme discomfort (Hasson & Barnes, 1989; Neufer, Costill, Flynn, Kirwan, Mitchell & Houmard, 1987). However, the role of the pre-exercise meal is less clear as the effects of the meal depend on the macronutrient composition, the type and amount of carbohydrate consumed, and the time between ingestion and exercise.

Current recommendations suggest pre-exercise meals include adequate carbohydrate (up to 100 grams) and be low in fat and protein (Hultman, Harris & Spriet, 1994; McArdle, Katch & Katch, 1991). Proteins and fats are limited due to the longer time in the digestive tract for digestion and absorption. Furthermore, McArdle et al. (1991) recommend eating at least three hours before exercise to provide adequate absorption of the meal. Harkins, Carey, Clark & Bernadot (1993) recommend a carbohydrate-rich meal two to three hours before exercise to allow for digestion and recommend additional time if the athlete is particularly anxious before the event.

None of these recommendations make a distinction in the type of carbohydrate recommended and yet different carbohydrates have significantly different physiological responses. Jenkins, Wolever, Taylor, Barker, Fielden, Baldwin, Bowling, Newman, Jenkins & Goff (1981) introduced the concept of the glycemic index (GI) to classify carbohydrates on the basis of their physiological response as opposed to the traditional categorization of simple or complex. A high glycemic index food illicits a higher blood glucose response than a food with a lower glycemic index. The glycemic index for individual foods has been found to correlate with the glycemic index of a meal (Chew, Brand, Thorburn, & Truswell , 1988). The glycemic index of the meal has direct implications for an athlete's choice of pre-exercise meals, since a concern of eating carbohydrate before exercising is the inducement of hyperinsulinemia. Hyperinsulinemia may inhibit the release of free fatty acids (FFA), increase muscle glycogenolysis and decrease time to exhaustion (Coyle, Coggan, Hemmert, Lowe, & Walters, 1985). Thomas, Brotherhood, & Brand (1991) and Hargreaves, Costill, Katz & Fink (1985) have proposed that low GI foods consumed before exercise may prevent hyperglycemia and the resulting hyperinsulinemia. Thomas et al. (1991) reported significantly increased plasma free fatty acids and times to exhaustion, and lower respiratory exchange ratio (RER), plasma lactate and insulin in trained cyclists who consumed low glycemic index meals one hour before exercise. Also, Hargreaves, Costill, Fink, King, & Fielding (1987) reported that a solution of fructose consumed 45 minutes before a cycling ride to exhaustion produced more stable blood glucose and insulin levels although no performance advantage was observed. Coyle & Coyle (1993) and Burke, Collier & Hargreaves (1993) have recently demonstrated the utility of the glycemic index in replenishing muscle and liver glycogen following exercise. Clearly, the glycemic index needs to be considered when measuring the impact of a pre-exercise meals on substrate utilization during exercise and performance.

Statement of the Problem

The purpose of this study was to investigate the effects of pre-exercise meals with differing glycemic indices on substrate utilization and endurance performance during cycle ergometry.

Hypotheses

The following research hypotheses were tested ($p<0.05$):

1. The pre-exercise moderate-glycemic meal will result in a reduced rate of lactate formation and elevated free fatty acids during exercise than the control or high glycemic index meal.

2. The pre-exercise moderate-glycemic meal will result in longer times to exhaustion than the control or high glycemic index meal during the graded maximal test following 60 minutes of moderate intensity cycling .

3. The pre-exercise moderate-glycemic meal will result in a lower RER during the first 30 minutes of exercise than the high glycemic index meal.

Delimitations, Limitations & Assumptions

This study was delimited to 10 healthy, physically active males aged 19 - 34 years from Colorado State University. A medical questionnaire was given to the subjects to determine their health status. It was assumed that the subjects avoided strenuous physical activity 24 hours prior to each trial and that they followed the recommended diet plans for three days before each trial. It was also assumed that the subjects performed to the best of their ability during each trial and that they maintained their usual activity level throughout

the study. Additionally, it was assumed that the equipment was calibrated and in proper working order for data collection.

Definitions

High Glycemic Indices:	Individual foods have GI above 90 Predicted meal GI of greater than 90
Moderate Glycemic Indices:	Individual foods have GI between 60 - 90 Predicted meal GI between 60 - 90
Low Glycemic Indices:	Individual foods have GI below 60 Predicted meal GI of less than 60

CHAPTER II

LITERATURE REVIEW

Considerable research has occurred over the past 20 years on the importance of dietary carbohydrate in athletic performance. Most attention has focused on modifying dietary carbohydrate to increase muscle and liver glycogen stores in hope of delaying the onset of fatigue, hypoglycemia and related symptoms of "hitting the wall." It is generally accepted that long-term consumption of a high carbohydrate diet during training will increase muscle and hepatic glycogen stores and thus provide the required fuel for prolonged exercise through glycogenolysis (Costill & Hargreaves, 1992; Hasson & Barnes, 1989; Horowitz & Coyle, 1993; Neufer et al., 1987; Sherman, Doyle, Lamb & Strauss, 1993).

The fuel used for exercise depends on the intensity and duration of the exercise. (Hagerman, 1992, Hasson & Barnes, 1989). Low-intensity (<50% VO_{2max}) exercise depends on both fat and carbohydrate oxidation with a greater percentage of fat oxidized during exercise of longer duration or lower intensity. At higher intensity (60-85% VO_{2max}), carbohydrate oxidation predominates (Hagerman, 1992; O'Brien, Viguie, Mazzeo & Brooks, 1993). Increasing exercise duration also increases glucose uptake by skeletal muscles. Thus, glucose utilization is increased with both duration and intensity of exercise.

The increased utilization of glucose by skeletal muscles is accompanied by an increase in hepatic glucose output; first from increased glycogenolysis and then from gluconeogenesis as exercise continues. A decrease in hepatic glycogen, muscle glycogen and glucose is highly correlated with a decrease in athletic performance at 60-85%

VO_{2max} (Costill & Hargreaves, 1992; Hargreaves & Briggs, 1988; Hasson & Barnes, 1989). Therefore, nutritional strategies are aimed at optimizing plasma glucose, and liver and muscle glycogen. There is general agreement that various carbohydrate loading regimens are effective during training to increase glycogen stores (Coggan & Swanson, 1992; Costill & Hargreaves, 1992; Harkins et al., 1993; Hultman et al., 1994). However, there is less consensus about the appropriate composition of the pre-exercise meal.

Pre-exercise Carbohydrate Consumption

Studies on the appropriate pre-exercise meal are numerous but conflicting. Differences in study design account for some of the inconsistencies. Meals and carbohydrates have been given 5 minutes (Neufer et al., 1987; Wilbur & Moffat, 1992), 30-60 minutes (Foster, Costill & Fink, 1979; Sherman, Peden & Wright, 1991; Thomas, Brotherhood & Brand, 1991) or three to six hours (Flynn, Michaud, Rodriguez-Zayas, Lambert, Boone, & Moleski, 1989; Neufer et al., 1987) before exercise. Additional differences include intensity level and exercise duration. Hasson & Barnes (1989) believe the different research strategies have arisen in an attempt to avoid hyperinsulinemia and hypoglycemia, conserve glycogen and improve endurance performance.

Pre-exercise meals are recommended to assure adequate hydration and to provide adequate carbohydrate energy by optimizing muscle and liver glycogen stores (Coggan & Swanson, 1992). There is a significant depletion of carbohydrate stores in the liver and muscles following an overnight fast (Hasson & Barnes, 1989). Current recommendations for pre-exercise meals are to include adequate carbohydrate (up to 100 grams) and be low in fat and protein. (Hultman et al., 1994; McArdle et al., 1991). Proteins and fats are limited due to prolonged time for digestion and absorption.

The timing of the pre-exercise meal may be critical. McArdle et al. (1991) recommend eating at least three hours before exercise to provide adequate absorption of

the meal. Harkins et al. (1993) recommend eating a carbohydrate-rich meal two to three hours before exercise as a general rule to allow for digestion, with additional time if the athlete is particularly anxious before the event. Flynn et al. (1989) examined the effects of eating four or eight hours before exercise on substrate utilization and hypothesized that increasing the fasting time before exercise might enhance FFA mobilization, reduce carbohydrate oxidation and improve performance. However, their results in seven trained male cyclists showed no significant differences in substrate utilization or performance.

A primary concern of eating carbohydrate just before exercising is the inducement of hyperinsulinemia. The negative effects of hyperinsulinemia include an inhibition of FFA's and increased muscle glycogenolysis (Coggan & Swanson, 1992). These effects are not seen when plasma glucose levels are within normal range. There is no consensus on the appropriateness of carbohydrate just prior to exercise and similar studies have yielded opposite results. Seifert, Paul, Eddy, & Murray (1994) fed cyclists carbohydrate solutions 45 minutes prior to 50 minutes of moderate-intensity exercise. Significantly elevated insulin levels at the beginning of exercise resulted in decreased glucose at 30 minutes of exercise but by 40 minutes of exercise, glucose and insulin were similar to baseline values. Brouns, Reher, Saris, Beckers, Menheere & Ten-Hoor (1989) found that consumption of various carbohydrate-containing beverages 20-30 minutes before exercise did not lead to rebound hypoglycemia but rather increased blood glucose. Conversely, Foster et al. (1979) reported that glucose ingestion 30 minutes before exercise resulted in significant hypoglycemia after 40 minutes of exercise. Decreased serum free fatty acids, another indicator of hyperinsulinemia due to inhibition of lipolysis, were also observed.

Research is limited on the effects of varying the types of carbohydrate in the pre-exercise meal and yet the type of carbohydrate consumed before exercise may also prove critical. Modification of the type of carbohydrate consumed before exercise has produced variable results. In a study of trained cyclists, Thomas et al. (1991) found that the

glycemic index of foods affected the time to exhaustion. Consumption of low glycemic index foods (lentils) one hour prior to exercise produced significantly increased plasma free fatty acids and times to exhaustion, and produced significantly lower RER, plasma lactate and insulin than high glycemic index feedings (potato, glucose). The improvements were thought to occur due to the ability of the low glycemic food to provide glucose without the stimulation of insulin release. The lower RER indicated greater FFA oxidation and may have indicated less muscle glycogen usage during the early stages of exercise, thus sparing them for use later in the exercise trial. Lower levels of lactate also suggested lower levels of glycolysis. The authors chose the one hour before exercise feeding time to allow for maximal changes in postprandial insulin and glucose prior to beginning exercise. The subjects were still in an absorptive state during most of each trial.

In another study investigating differences in glycemic indices, Hargreaves et al. (1985) reported that a solution of fructose consumed 45 minutes before a cycling ride to exhaustion produced more stable blood glucose and insulin levels. However, there was no performance advantage nor any change in muscle glycogen utilization. A different study design was utilized by Horowitz and Coyle (1993) to investigate metabolic responses to pre-exercise meals with different types of carbohydrate and fat. The results indicated that moderate glycemic foods (rice, potatoes mixed with margarine) consumed 30 minutes prior to exercise may confer an advantage over high GI foods (potatoes, sugar, confectionery bar). All foods produced a glucose lowering effect during the first 30 minutes of exercise but the high GI foods produced significantly lower glucose levels than the moderate GI foods. However, the authors noted that the GI index of the pre-exercise meal did not affect the sensation of fatigue or the ability of the subjects to finish 1 hour of cycling at 50-70% VO_{2max}. In agreement with this, Paul, Layman, Boileau, Rokusek, & Dykstra (1993) fed a group of 6 men and 6 women meals consisting of milk plus different cereals providing 370 calories for the men and 280 kcals for the women. The lower GI

cereal (oatmeal) produced lower insulin levels after 20 minutes of exercise when compared to corn flakes and wheat flakes. The higher insulin levels from the high GI cereals resulted in significant decreases in plasma glucose levels. However, the type of carbohydrate consumed did not affect performance times or post-exercise recovery.

The Glycemic Index

For years, carbohydrates have been classified as either simple or complex with nutritionists recommending athletes consume a greater percentage of complex carbohydrates. Harkins et al. (1993) recommend pre-exercise or pre-competition meals should "emphasize complex carbohydrates because they are quickly digested and absorbed." However, Jenkins et al. (1981) introduced the concept of the glycemic index to classify carbohydrates on the basis of their physiological response as opposed to the traditional categorization of "simple" or "complex." The glycemic index was calculated from the blood glucose response to a standardized amount of food and compared to the response curve from the reference food, either glucose or white bread. Although individuals may have vastly different responses to a food, the glycemic index is normalized for each subject's response to the standard food. Thus, differences among individuals are removed and the glycemic index of individual foods are the same in diabetic and non-diabetic subjects (Wolever, Jenkins, & Josse, 1991). The glycemic index of a given food is primarily related to the digestion and absorption of the carbohydrate. Factors involved include the type of starch (amylopectin/amylose ratio), the nature of saccharides, the physical form of the food, cooking and processing techniques and the fiber content and type. Sample glycemic indices of different carbohydrates are displayed in Table 1 and it is clear that different complex carbohydrates produce significantly different glycemic responses. Many of the traditional complex carbohydrates consumed by athletes have a high glycemic response which could trigger hyperinsulinemia and hypoglycemia.

Table 1: Glycemic Indices (GI) of Carbohydrates

High GI Carbohydrates		Moderate GI Carbohydrates		Low GI Carbohydrates	
Wheat Bread (WW)	100	Oatmeal	89	Lentils	36
Corn Flakes	121	White Rice	77	Kidney Beans	38
Shredded Wheat	97	Spaghetti	67	Milk (skim)	46
Baked Potato	116	Banana	84	Apple	52

Values expressed in comparison to the standard of white bread = 100 (Wolever, et al., 1991).

Thomas et al. (1991) and Hargreaves et al. (1985) proposed that low GI foods consumed before exercise may prevent hyperglycemia and the resulting hyperinsulinemia. Some concern with the glycemic index involves the application of GI values for individual foods to mixed meals which include greater fat and protein. Fat and protein influence glycemic response by delaying gastrointestinal transit. However, in a study using mixed meals with 15% protein and 30 % fat in non-diabetic subjects, Chew et al. (1988) found that the glycemic indices for various meals correlated well with the predicted glycemic indices. The predicted meal values were obtained by summing the percent of carbohydrate contributions of each carbohydrate-containing food multiplied by the published glycemic index value for each food. The carbohydrates used in the meals included bread, lentils, potatoes, pasta, chick peas and rice.

While some criticisms of the glycemic index remain, Wolever et al. (1991) argue that numerous studies support the clinical utility of the GI index in non-diabetic individuals. In fact, Coyle & Coyle (1993) recommend using the glycemic indices of foods to determine the appropriate carbohydrates to consume post-exercise to replenish glucose and glycogen stores. The authors maintain that 50 grams of moderate or high glycemic foods every 2 hours postexercise are necessary to aid glycogen synthesis. Other researchers have also recommended distinctions between carbohydrate types based on the

glycemic index. In a study of five well-trained cyclists, Burke et al. (1993) reported that the increase in muscle glycogen content was significantly greater after consuming a high GI diet following depletion trials than with a low GI diet. Clearly, the traditional classification of carbohydrates as simple or complex is inadequate in forming nutritional recommendations for endurance athletes.

CHAPTER III

METHODS AND PROCEDURES

Prior to beginning this study, approval was obtained from the Colorado State University Human Research Committee (Appendix A). Each subject was informed of the study protocol, procedures, risks and benefits before they signing an informed consent form (Appendix B). The subjects were informed that they could withdraw from the study at any time without prejudice.

Subject Selection

10 active males between the age of 19-34 years participated in this experiment. A medical questionnaire (Appendix C) was used to eliminate subjects who were smokers, were at risk for cardiovascular disease or were taking medication. Subjects were instructed not to change their exercise duration or intensity during the study and to limit exercise the day before each trial. Participants were also advised to abstain from consuming caffeine and alcoholic beverages 24 hours before each trial. A Registered Dietitian instructed subjects to follow a moderate-high (55-60%) carbohydrate diet throughout the experimental period, particularly the three days before each trial, to ensure adequate liver and muscle glycogen stores prior to exercise. They were further trained to keep accurate 3-day food records. Food records from the first and last trials were analyzed using the Nutritionist III (N-Squared Computing, Salem, OR) diet analysis program to quantify differences in macronutrient intake between trials. To eliminate confounding effects of altitude on $\dot{V}O_{2max}$, subjects were required to reside in the local area for at least six weeks prior to and throughout the investigation.

Research Design

Each subject performed three randomized trials at one week intervals. Each trial consisted of an overnight fast prior to a morning meal followed by a submaximal and maximal performance test on the cycle ergometer. Prior to the trials, all subjects were given a graded maximal exercise test to determine baseline VO_{2max}.

Subjects reported to the laboratory in the morning following an overnight fast (10-12 hours). Upon arrival, the subjects were weighed and then fed a meal containing 100 grams of carbohydrate (77% carbohydrate) and consisting of typical breakfast foods with different glycemic indices. Meal composition is given in table 2. A third trial using a continued fast served as a control. Meals were provided in a random order. After consumption of the meal, the subjects were seated for the one hour prior to the performance test.

Table 2: Test meal composition:

High GI Meal	Moderate GI Meal
58 gms Corn Flakes cereal	430 gms cooked oatmeal
140 gms ripe banana	200 gms ripe banana
371 gms 1% fat Milk	155 gms 1% fat milk
510 kcals	505 kcals
101 gms CHO (78% of kcals)	100 gms CHO (77% of kcals)
18.4 gms Prot (14% of kcals)	18.5 gms Prot (14% of kcals)
4.8 gms Fat (8% of kcals)	5.5 gms Fat (9% of kcals)
3.4 gms Dietary Fiber	7.1 gms Dietary Fiber

Maximal and Submaximal Exercise Testing

Each subject was first tested for maximal oxygen uptake (VO_{2max}) using a modified American College of Sports Medicine protocol for the cycle ergometer with a progressive maximal workload. An electrically braked Lode Excalibur bicycle ergometer (Groningen-Nederland) was used. Resting data was collected two minutes before the start of the test with the subject seated quietly on the cycle ergometer. A two-minute

warm-up period began with the subject pedaling at 80-100 rpm against a zero work load. The work load was then increased 25 watts every 60 seconds until the subject could no longer meet the minimum cadence required (20 rpm), or until there was no further increase in oxygen uptake with increasing workloads. This maximal test was used to calculate 70% of each subjects VO_{2max} which was set as the intensity level for subsequent trials.

Each trial consisted of a 60 minute submaximal test at 70% VO_{2max} followed by a performance/maximal test to measure time to exhaustion. One hour after meal consumption, the subjects cycled for 60 minutes on the cycle ergometer at a work load which corresponded to 70% of their VO_{2max}. Subjects reached this intensity within 10 minutes. After 60 minutes, the workload was increased 25 watts every 2 minutes until the subject could no longer continue. The workload was then dropped to 50 watts while subjects cooled down until their heart rate dropped below one hundred and twenty beats per minute. Subjects were provided water as needed and encouraged to drink throughout the trial to minimize dehydration. The performance laboratory was maintained at 23 ± 1° C and 55-65% humidity. During the exercise periods, an electric fan was directed on the subject. Heart rate and respiratory gases were collected for four minutes every 15 minutes and averaged over a 2 minute period.

Blood Sampling

Blood was drawn at pre-meal, pre-exercise, every 15 minutes of exercise and at the end of the maximal test to exhaustion from a superficial forearm vein with a flexible, indwelling catheter fitted with a three-way valve. All samples consisted of five ml of venous blood drawn into heparin solution (1000 USP units/ml - Solopak Laboratories, Franklin Park, IL). A microhematocrit tube was filled with whole blood directly following each sample to determine hematocrit. Immediately after each trial was

completed, plasma was recovered by centrifugation (Angle Centrifuge #1500 - Hamilton Bell Co., Montvale, NJ) at 3000 rpm for 20 minutes and then stored at -70° C.

Assay Methods

Plasma glucose concentration was measured by a glucose oxidase/peroxidase method using a Sigma kit (Sigma Chemical Co., St. Louis, MO).

Plasma lactate was measured using a modification of the enzymatic fluorometric method of Loomis (1961). The method utilizes the enzymatic conversion of lactate to pyruvate with 50 units lactate dehydrogenase (from rabbit muscle) at pH 9.2 in 5mM hydrazine, and 2.25 mM NAD. The assay is an end-point assay which employs hydrazine to trap the reaction product in order to shift the equilibrium toward pyruvate synthesis. The reaction produces NADH from NAD on an equimolar basis with the conversion of lactate to pyruvate. NADH was quantitated fluorometrically using a Farrand fluorimeter equipped with filters to provide an excitation maximum at 370 nm and an emission wavelength of 450 nm. The concentration of lactate in plasma was determined against a five-point standard curve (1-5μmol/l lactate in a .5 ml volume in each assay).

Plasma free fatty acids were measured using the enzymatic method of Shimuzu, Inoue, Tani, & Yamada (1979). This end-point method is based on the activation of plasma free fatty acids to fatty acyl-CoA derivatives by acyl-CoA synthetase (ACS) in the presence of myokinase (MK) to shift equilibrium toward acyl-CoA formation. Excess CoA is removed by the addition of ethylmalenamide to prevent CoA interference with color development. Activated fatty acyl-CoA is oxidized by the action of acyl-CoA oxidase (ACO) to yield fatty enoyl-CoA plus H_2O_2. The peroxide is oxidized in the presence of phenol and 4-aminoantipyrene by peroxidase to form a red quinoneimine dye which can be quantitated spectrophotometrically at 500 nm. Twenty microliter aliquots of undiluted plasma were pre-incubated at a pH of 7.4 for 5 minutes at 37° C in the

presence of CoA, ATP, magnesium, ACS, and MK (final concentration of .75 mmol/l CoA, 2mmol/l ATP, .52 mmol/l Mg+2, 47 mol/l KCl-, 308U/l ACS, 3.1 U/l MK, 46 mmol/l Tris, and 99 mg/l Triton X-100). N-ethylmaleinamide (final concentration 1.2 mmol/l) and phenol (12.5 mmol/l) were added to stop the reaction and trap unreacted CoA. The colormetric reaction using 4-aminoantipyrene, ACO, and peroxidase (final concentration .17 mmol/l 4-aminoantipyrene, .33 kU/l ACO, 5 kU/l peroxidase, 50 mmol/l potassium phosphate, pH 7.4) was carried out for 10 minutes at 37°C. Absorbance was read on a Gailford Response spectrophotometer at 500 nm against a reagent blank. Plasma free fatty acid concentration was quantified against a standard curve (.0125-2 mmol/l sodium palmitate).

Measurement of Respiratory Gases

Respiratory gases were obtained with an open circuit, indirect, calorimetric system (Sensormedics Metabolic Measurement Cart, model 2900, Sensormedics Corporation, Yorba Linda, CA). The Sensormedics cart measured ventilation (VE), carbon dioxide production (VCO_2 ml·min^{-1}), oxygen consumption (VO_2 l·min^{-1}), oxygen consumption in milliliters per kilogram of body weight (VO_2, ml·kg^{-1}·min^{-1}), and the respiratory exchange ratio (RER). During testing, subjects were equipped with a nose clip and inhaled ambient room air through a Hans Rudolph three way valve into the cart. Prior to each test, the cart was calibrated with gases of known concentration and a known volume of atmospheric air. Ambient temperature, barometric pressure and relative humidity were recorded prior to testing so that volumetric corrections could be made in calculating metabolic data. Heart rate was measured using a UNIQ CIC Heartwatch monitor, model 8799 (Computer Instruments Corporation, Hempstead, NY).

Data Analysis

Data were reduced using the Statistical Package for the Social Sciences (SPSS) (Nie, Hall, Jenkins, Steinbrenner & Bent, 1970; Norvis, 1990). Subject characteristics were averaged. Food records were analyzed using the Nutritionist III diet analysis program to quantify differences in macronutrient intake during the first and third weeks. The experimental pre-exercise meals were also analyzed to identify differences in macronutrient composition. Mean differences on repeated measures of glucose, lactate, FFA, VO_2, VCO_2, RER and heart rate during the sub-maximal trial were compared using a randomized block analysis of variance with repeated measures. A one-way analysis of variance was used to determine differences between mean times to exhaustion as well as differences in glucose, lactate, FFA, VO_2, VCO_2, RER and heart rate collected at exhaustion. Tukey's post-hoc analysis was used to determine specific differences. Alpha was set at $p<0.05$.

CHAPTER IV

RESULTS

10 active males between the ages of 19-34 years participated in this experiment. The subjects were aerobically fit as evidenced by a mean VO_{2max} greater than 60 $ml \cdot kg^{-1} \cdot min^{-1}$. Subject characteristics are listed in Table 3. All subjects were weight stable throughout the experimental period. All subjects completed the three trials consisting of a 60-minute submaximal ride followed by a graded maximal test to exhaustion. Blood could not be drawn consistently from one subject. Therefore, blood data exists for nine subjects. There was no significant difference ($p>0.05$) in exercise intensity maintained during the submaximal trial between the experimental periods (68.4% VO_{2max} for moderate GI, 68.9% VO_{2max} for fast and 68.6% VO_{2max} for high GI).

Table 3: Subject Characteristics

Subject Characteristics	Mean ± SEM
Age	22.9 ± 1.4
Weight (kg)	71.8 ± 3.2
Height (cm)	178.3 ± 2.5
max VO2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	60.5 ± 2.6
max VO2 ($l \cdot min^{-1}$)	4.4 ± 2.9

The analysis of the subject's three-day food journals kept prior to the first and third exercise tests is summarized in Table 4. No significant differences in macronutrient concentration existed between the first and third trial and subjects appeared to have followed the diet recommendations.

Table 4: Nutrient analysis of subject's 3-day food journals

Diet Component	First Trial (mean±SEM)	Final Trial (mean±SEM)
Kilocalories	2914.4±146.1	2814.4±135.3
Carbohydrate (gm)	428.0±26.0	436.7±22.7
% Carbohydrate	58.0±3.0	61.3±2.0
% Protein	13.3±1.3	12.7±0.9
% Fat	26.2±2.0	23.2±1.4

Submaximal Results

Plasma glucose responses during the submaximal ride are presented in Figure 1.

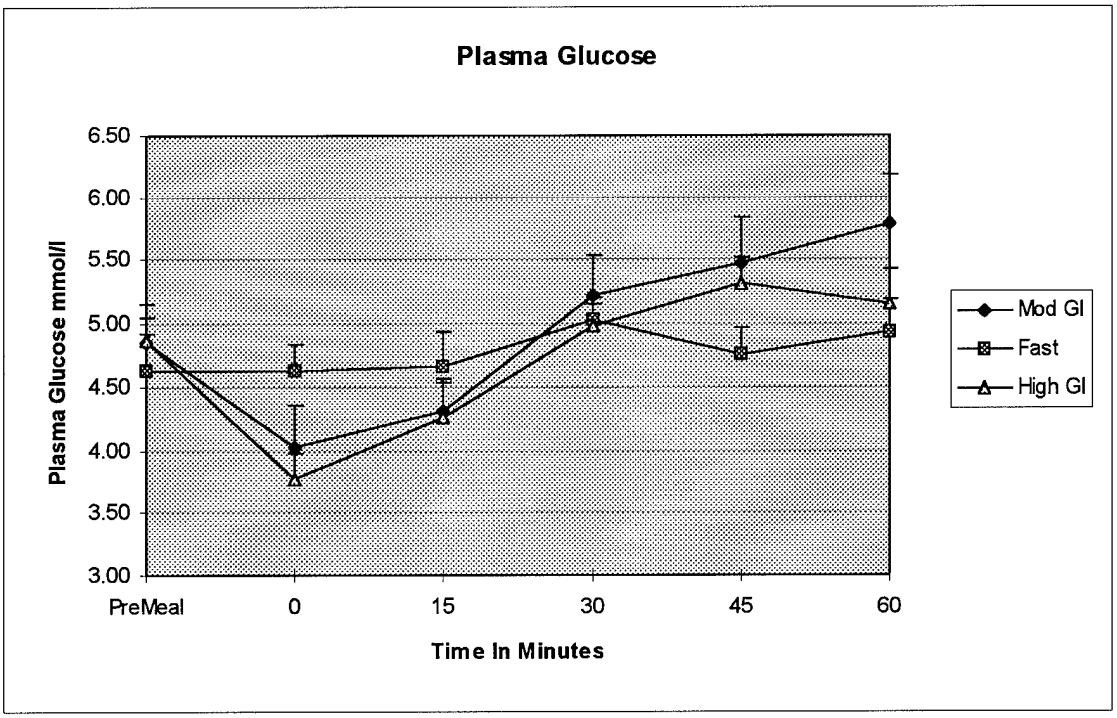


Fig. 1: Venous plasma glucose levels at selected time intervals following three treatments

There were no significant differences between treatments in fasting plasma glucose. Prior to the beginning of exercise, however, the high GI meal trial resulted in significantly lower ($p=.018$) glucose values than the fasted trial. The moderate GI trial was intermediate with respect to the high GI meal and fast but was not significantly different from the fast. Glucose levels at 45 and 60 minutes of submaximal exercise were higher with the moderate GI treatment then either the high GI or fasted trial although the values

were not statistically significant. No further significant interactions were observed during the submaximal trial. There were significant changes with time as glucose declined significantly ($p<.001$) at the beginning of exercise and increased significantly ($p<.001$) at 30 minutes in fed but not in fasted trials.

Results for plasma free fatty acids are presented in Figure 2. There was a significant treatment by time interaction ($p=.037$) at the 0 and 15 minute intervals as the moderate GI meal resulted in a rise in plasma FFA concentration while the fasted and high GI trials lowered FFA. Furthermore, plasma FFA increased significantly with time at 30 minutes ($p=0.016$) before plateauing for the remainder of the submaximal ride. No significant treatment effects were observed from 30 to 45 minutes. At the end of submaximal exercise, FFA were highest in the moderate GI trial and lowest in the high GI trial but these differences were not statistically significant.

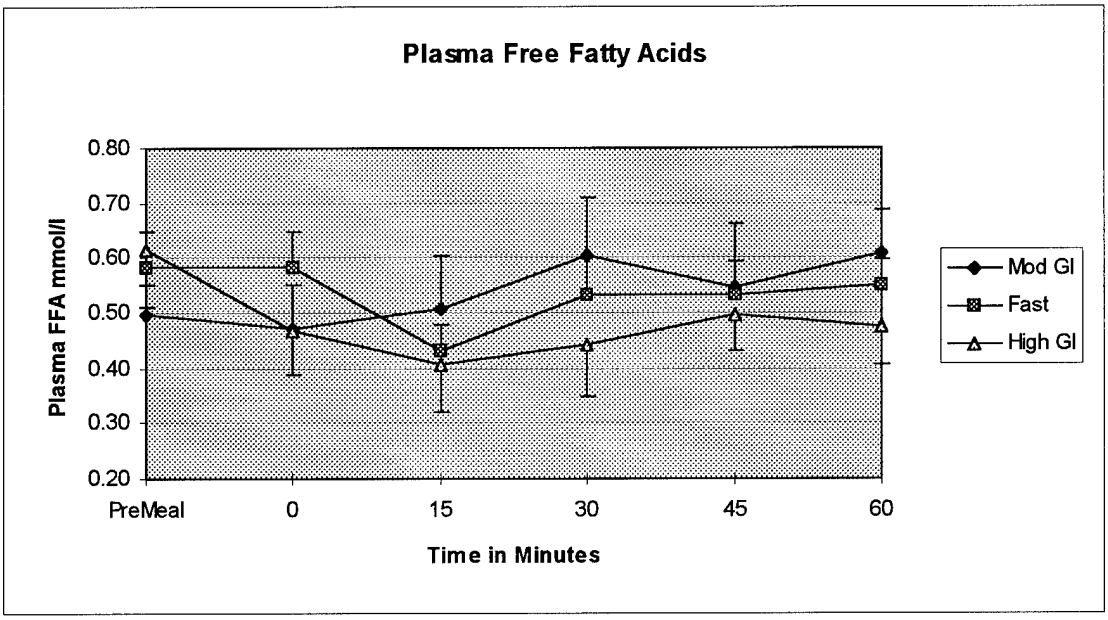


Fig. 2: Venous plasma FFA levels at selected time intervals following three treatments

No significant treatment effects on plasma lactate were observed (Fig. 3). Fasted lactates levels were not significantly different but there was a significant increase in lactate

($p<.001$) from the beginning of exercise to the 15 minute point. Lactate levels exhibited a plateau after 15 minutes of exercise with all treatments and did not change significantly for the remainder of the submaximal trial.

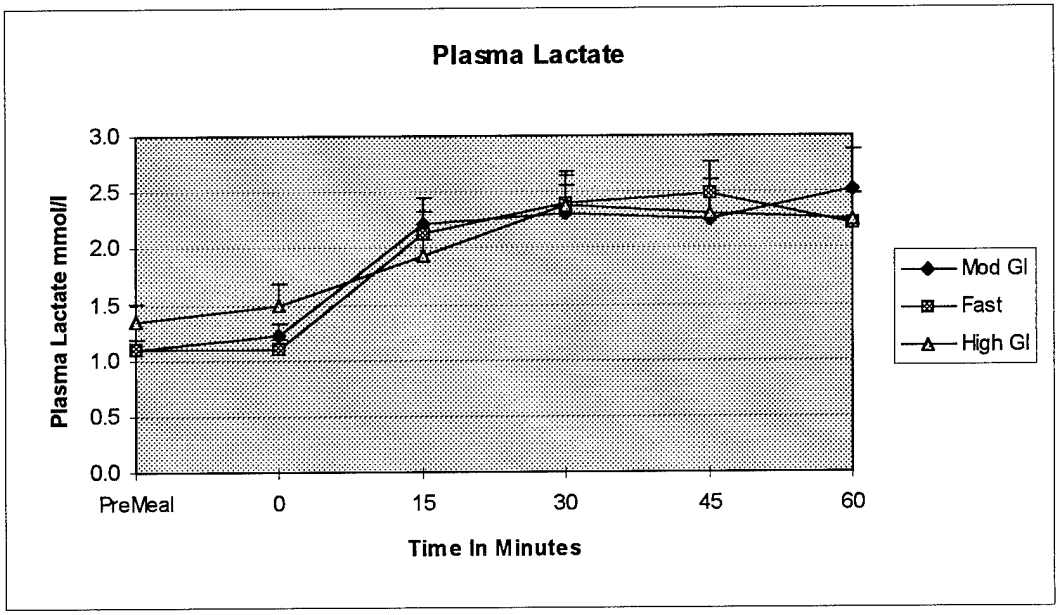


Fig. 3: Venous plasma lactate levels at selected time intervals following three treatments

Mean scores for RER data, collected at 15, 30, 45 and 60 minutes of the submaximal test, are presented in Figure 4. There were significant treatment effects at all times of submaximal exercise with fed trials producing significantly higher ($p<.001$)

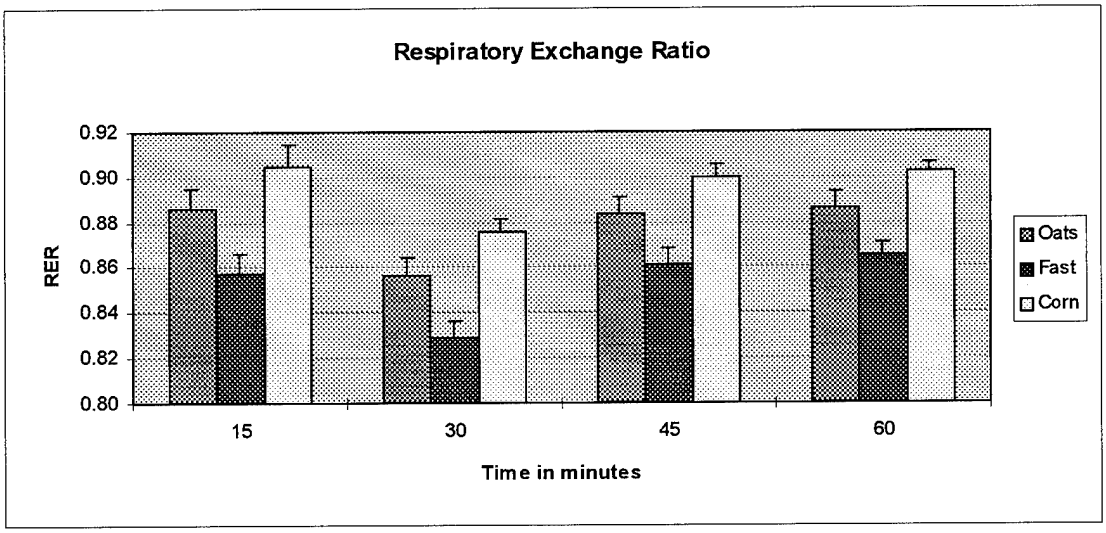


Fig. 4: Respiratory exchange ratio response during exercise for the three treatments.

RER than fasted trials, and the high GI meal significantly higher than the moderate-GI meal. The rank order of the trials remained the same throughout with the high GI meal resulting in the highest RER followed by the moderate GI meal and then the fast. Significant changes occured with time as RER decreased from 15 minutes to 30 minutes ($p<.001$) and then increased significantly from 30 to 45 minutes ($p<.001$).

Heart rate (Figure 6) increased significantly with time, increasing significantly from 15 to 30 minutes ($p<.001$), from 30 to 45 minutes ($p=.043$) and from 45 to 60 minutes ($p=.019$). However, no significant treatment effects on heart rate were observed at any point during the submaximal trial.

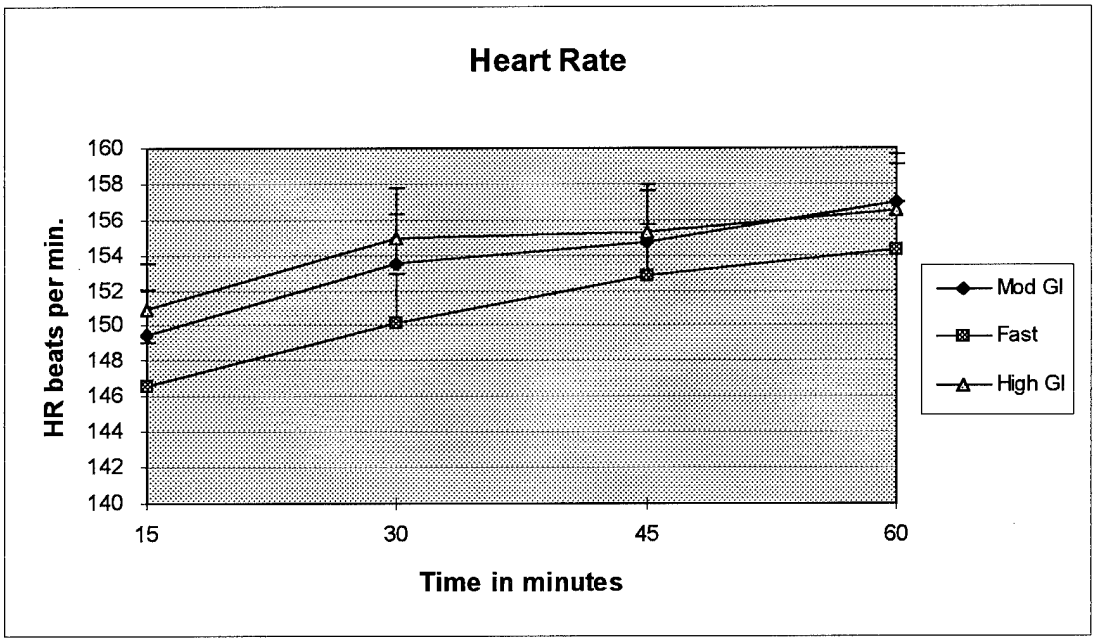


Fig. 5: Heart rates during submaximal exercise for the three experimental conditions.

There were no significant changes in V_E (Fig. 6), VO_2 (Fig.7) or VCO_2 (Fig. 8) throughout the 60 minute submaximal trial and no significant time by treatment interactions. Subjects maintained 68-72% $VO_{2\ max}$ throughout the trial.

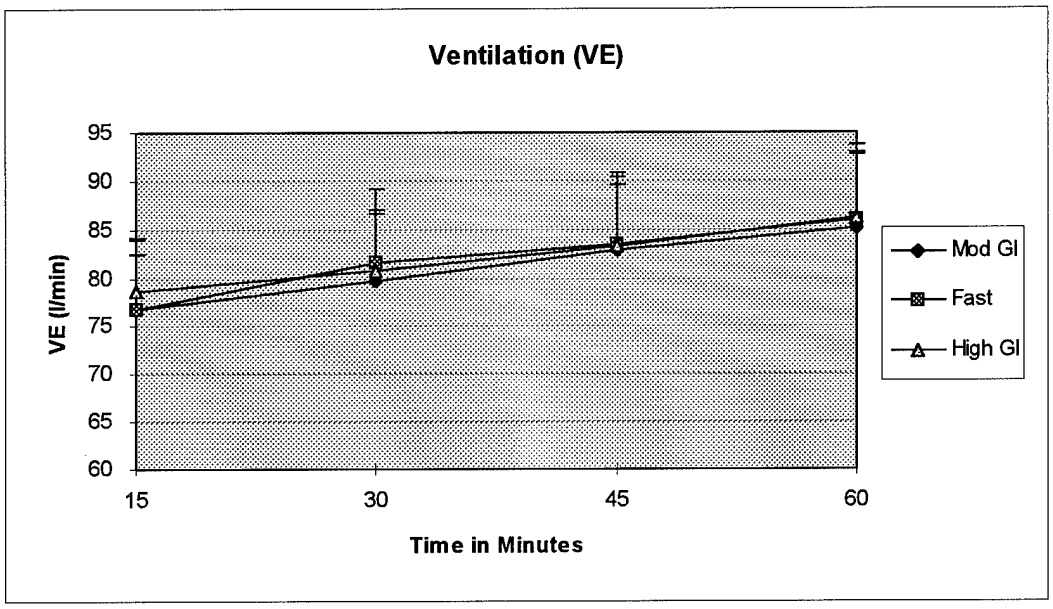


Fig. 6: Ventilation (VE) during submaximal exercise following three treatments.

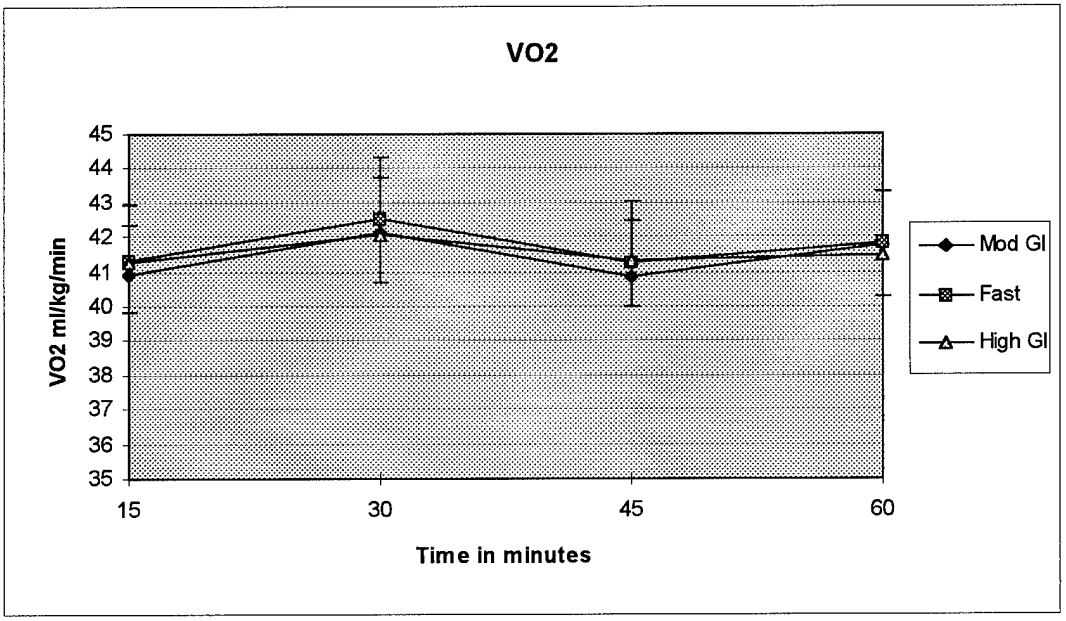


Fig. 7: Oxygen consumption during submaximal exercise following three treatments.

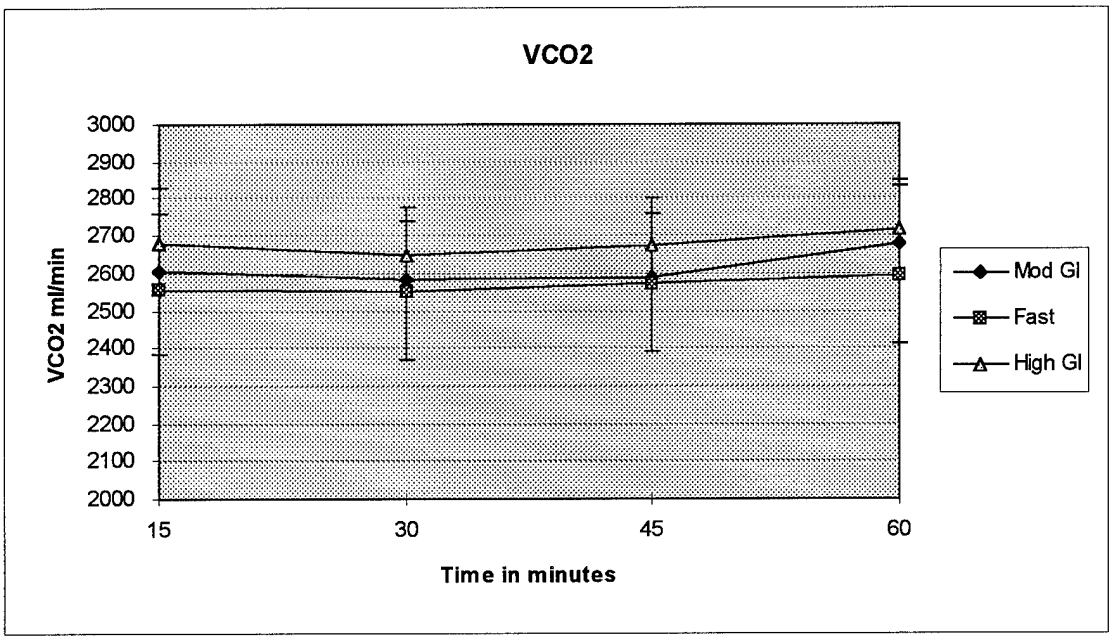


Fig. 8: Carbon dioxide production during submaximal exercise following three treatments.

Maximal Test to Exhaustion

Plasma glucose, FFA and lactate at exhaustion are presented in Figure 9. Glucose for the moderate and high GI trials were both higher than fasted glucose values at exhaustion but the differences were not significant ($p>0.05$) There were no significant differences in FFA or lactate levels at exhaustion. Data from respiratory measurements taken at the end of the maximal performance trial are displayed in Table 5. No significant treatment effects were observed at max between VO_2, VCO_2, V_E, HR, work output (watts), or RER. Times to exhaustion are represented in Figure 10. The times ranged from 5.32 to 10.75 minutes but there was no significant difference between experimental conditions. The mean VO_2 at exhaustion following the maximal performance test was 94% of $VO_{2\ max}$ measured at the beginning of the study.

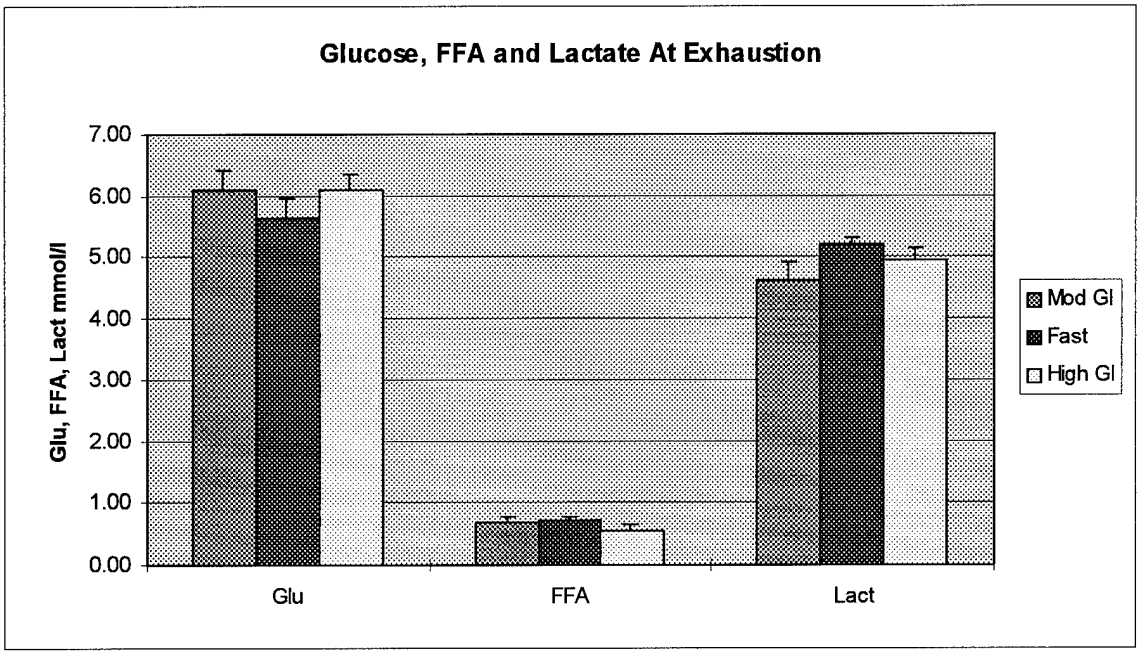


Fig. 9: Plasma glucose, FFA and lactate levels at exhaustion following graded maximal exercise.

Table 5: Respiratory Measures and Work Output at Exhaustion (Mean ± SEM)

	Moderate GI Meal	**Fasted Trial**	**High GI Meal**
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.36 ± 2.4	57.76 ± 2.0	56.65 ± 2.1
VCO_2 ($ml \cdot min^{-1}$)	4267 ± 173.9	4309 ± 221.6	4307 ± 172.5
VE	160 ± 12.0	164 ± 12.4	153 ± 10.3
HR	183.1 ± 2.9	183.2 ± 3.3	181.7 ± 2.9
Watts	306.0 ± 15.2	311.5 ± 17.2	303.5 ± 14.6
RER	1.09 ± 0.01	1.07 ± 0.02	1.08 ± 0.01

CHAPTER V

DISCUSSION

The purpose of this study was to determine the effects of commonly eaten pre-exercise meals with different glycemic indices on substrate utilization and exercise performance during cycle ergometry. There is considerable agreement about the importance of maintaining carbohydrate availability during exercise. Numerous studies (Coggan & Swanson, 1992; Coleman, 1994; Costill & Hargreaves, 1992) confirm the rationale for consuming carbohydrate-based sport drinks during extended exercise to provide a ready source of glucose to extend and enhance performance. The current study has meaningful implications for pre-exercise meal recommendations since an appropriate pre-exercise meal could provide a separate source of glucose and continue to be absorbed throughout a prolonged event. This might be especially important in activities such as long-distance swimming where sports drinks are difficult to ingest.

A previous study (Thomas et al., 1991) indicated that the glycemic index of a food might affect endurance performance but the effects of individual foods and not complete meals were investigated. Additionally, lentils were the low GI food, a food unlikely to be consumed in the early morning when pre-exercise and pre-game meals are often eaten, and an impractical choice for most athletes. Using common breakfast cereals, results from the current study indicate that both fed trials resulted in significantly higher carbohydrate oxidation as evidenced by higher RER ($p<.001$) with the moderate GI meal significantly lower than the high GI meal but higher than the fast. Thus, the experimental meals, standardized for kilocalories, carbohydrate, protein and fat but with differing glycemic indexes, produced significantly different rates of carbohydrate oxidation. Using white

bread as the standard, corn flakes have a GI of 121 while oatmeal has a GI of 89, a difference of 36%. Oatmeal has more protein, fat and dietary fiber than corn flakes, all of which serve to delay digestion and absorption of the starch and result in a lower glycemic response. Wolever et al. (1991) demonstrated that the glycemic index of the meal can be calculated to predict the response of the meal using a weighted mean of the GI values of the individual foods. For the experimental meals in this trial, the high GI meal had a predicted GI of 96 while the moderate GI had a predicted GI of 84 (Table 5), a difference of ~14%. In a more recent study, Thomas, Brotherhood and Miller (1994) experimented using meals with a three-fold difference in GI, using an experimental lentil-based flake cereal as their low GI meal with a potato-based flake cereal and a rice-based breakfast cereal as their high GI meals. However, the authors controlled only for available carbohydrate and did not control for other macronutrients. The meals had significant differences in their kcal, protein and fat content and all are potential confounding factors in a meals glycemic response.

Table 5: Predicted Meal GI

	Carbohydrate (gm)	**Ind. Food GI**	**Calc. Meal GI**
Corn Flakes	49.8	121	60
Milk (1% Fat)	32.8	84	27.7
Banana	17.8	48	8.5
Total	100.4	-	96.2
Oatmeal	46.5	89	41.4
Milk (1% Fat)	46.8	84	39.3
Banana	7.5	48	3.6
Total	100.8	-	84.3

Results of the present study for plasma glucose are in contrast to studies which show a nadir 15-20 minutes after beginning exercise (Horowitz & Coyle, 1993; Seifert et al., 1994; Sherman et al., 1991; Thomas et al., 1994). Both fed trials produced significantly lower glucose levels at the beginning of exercise. Glucose then rose steadily

throughout the exercise period, exceeding pre-meal levels after 30 minutes of exercise, due to an increased hepatic glucose output or an increase in glucose absorbed from the gut. Although no statistically significant differences in plasma glucose existed at any point between the two experimental meals, the moderate GI meal tended to be intermediate with respect to the high GI meal or control at the beginning of exercise and higher than both during late exercise. None of the subject's during any of the trials experienced any symptoms of hypoglycemia such as nausea, lightheadedness or weakness even though glucose levels were significantly lower at the beginning of exercise than before the meal. Pre-exercise meals typically result in higher glucose levels which stimulate a greater release of insulin. When exercise begins 30-60 minutes after a meal, the synergistic effect of high insulin and muscle contractions cause greater glucose uptake and a lowering of plasma glucose below fasted samples. Studies of pre-exercise meals given 30-60 minutes prior to exercise frequently, but not always, show that glucose reaches a nadir at the 15-20 minutes of exercise (Coggan & Swanson, 1992). From that point, glucose may remain depressed, return to fasted levels, or may increase beyond pre-exercise levels (Brouns et al., 1989; Coyle et al., 1985; Foster et al., 1979; Horowitz and Coyle, 1993; Neufer et al., 1987; Sherman et al., 1991; Thomas et al., 1994). The discrepancies may be a result of different exercise protocols, different types or amounts of carbohydrate and differences in time between exercise and meal consumption. Data from the current study indicated plasma glucose levels reached their lowest level prior to beginning exercise and rose steadily throughout the 60-minute submaximal trial.

The lack of significant treatment effects on blood glucose may have been because the performance time for the cycling trials was of insufficient duration to detect differences since carbohydrate is typically not a limiting factor in exercise less than 2 hours (Coggan & Swanson, 1992). However, Thomas et al. (1994) did observe significant differences between treatments early in exercise (0-30 minutes of exercise) of the approximate 2 hour cycling trial to exhaustion in their experiment with the lentil based meal. Using analysis of

covariance, the glycemic index of a meal was inversely related ($r = -0.97$, $p < 0.05$) to glucose concentrations at the end of the trial. Specifically, a 10 increment difference in glycemic index was "associated with a 0.2 mmol/L difference in plasma glucose concentration at the end of exercise." The present data had the same pattern of glucose response early in exercise but there was no significant differences at the end of the submaximal or maximal trial, even though glucose was higher after 60 minutes of submaximal exercise with the moderate GI meal. A difference might have been observed with a longer trial.

Significant treatment effects upon free fatty acids appeared to exist early in exercise. The moderate GI meal resulted in a significant increase ($p=.037$) in FFA after 15 minutes of submaximal exercise, while the high GI meal inhibited the rise. This trend continued through 30 minutes of exercise although the differences between treatments were not significant. The importance of changes in free fatty acids during exercise are uncertain. Generally, the concentration of FFA in plasma is proportional to the rate of FFA oxidation. Some authors (Costill, Coyle, Dalsky, Evans, Fink, & Hoopes, 1977) have theorized that higher FFA during exercise will result in higher fat oxidation, spare CHO sources and result in improved performance. Although not significant, the moderate GI meal resulted in higher FFA's than the high GI meal. This trend is in agreement with Thomas et al. (1994) who reported that low GI meals produced significantly higher FFA's near the end of 2 hours of cycling at 70% $VO_{2\ max}$. The implication is that the low GI meal increases availability of substrate since both glucose and FFA are higher than after a high GI meal. Interestingly, however, the current data are in opposition to the findings of Ritz, Krempf, Cloarec, Champ & Charbonnel (1991) in their study of 6 men at rest. Glucose, FFA and insulin were measured over a 6 hour period using a ventilated hood after consumption of the 50 gram glucose equivalents of either a high GI food (glucose solution) or low GI food (manioc starch). Free fatty acid concentrations were lower after eating the low GI food with corresponding higher glucose levels and glucose oxidation in

the third and fourth hours following consumption. These findings are difficult to reconcile with current data and the findings of Thomas et al. (1991, 1994). The differences may be due to the effects of the counter-regulatory hormones released during exercise since Ritz et al. (1991) examined subjects at rest. Additionally, Ritz et al. (1991) did not report significant differences until the third and fourth hours while the current data was collected within two-and-a-half hours of meal consumption.

RER in the fed trials was high as indicated by a mean RER of .90 with the high GI meal and .88 with the moderate GI meal. This compares to the fasted mean RER of .85. The high RER following consumption of a high carbohydrate meal is expected (Hagerman, 1992). The highest RER was seen with the high GI meal, significantly ($p<.001$) higher than the moderate GI meal and the fasted trial. The moderate GI meal yielded RER values lower than the high GI meal but significantly higher ($p<.001$) than the fast. A lower RER would reflect higher relative oxidation of fat and might represent a conservation of glycogen stores. Thus, a meal that would provide glucose throughout exercise but not raise CHO oxidation excessively might be of benefit. Thomas et al. (1991) demonstrated that high GI foods resulted in a higher RER, with low GI foods (lentils) and fasted subjects having the lowest RER. In a follow-up study in 1994, Thomas et al. (1994) reported higher RER with high GI meals and lower RER with low GI meals. It was theorized that the lower RER may have indicated lower muscle glycogen usage which may have helped to prolong exercise, although muscle biopsies were not performed. Jansson & Kauser (1982) demonstrated that a lower RER and the increased relative oxidation of fat did spare glycogen stores during 25 minutes of exercise at moderate intensity (65% $VO_{2\ max}$). Research is equivocal, however, as others have reported decreased performance with lower RER values and higher FFA concentrations (Coggan, 1991). In fact, Hargreaves & Briggs (1988) reported that higher FFA concentrations did not increase FFA uptake or result in RER changes. Furthermore, trained athletes have lower FFA concentrations than the untrained which has been attributed to training

adaptations which enhance fatty acid metabolism (Muoio, Leddy, Horvath, Awad & Pendergast, 1994). Data from the present study does not provide any insight since differences in RER did not produce differences in performance.

There was a large amount of variability among subjects in the current study in response to different treatments, indicative of the individual variability in the glycemic response to foods. Dunford and Saunders (1994) fed three male endurance athletes at rest 50 gram portions of either orange juice, oatmeal or graham crackers and then measured the plasma glucose response. The average response 30 minutes after consumption was reflective of the food's GI. Graham crackers yielded the highest glucose response followed by orange juice and then oatmeal. However, the responses were different for each subject for each trial and two subjects had similar glycemic responses but to different foods. The small sample size limits any conclusions but it does highlight the individual variability in glycemic response and concurs with the individual variability seen in this study.

Initial glycogen concentrations may also be a factor in the variability seen among the subjects. Widrick, Costill, Fink, Hickey, McConnell, & Tanaka (1993) studied eight cyclists who performed four self-paced time trials which lasted over 2 hours. The four trials were performed under conditions of high muscle glycogen stores with and without carbohydrate feeding or low glycogen stores with and without carbohydrate feedings. The low glycogen plus carbohydrate condition resulted in performance equal to the two high glycogen trials. However, low glycogen stores without carbohydrate resulted in significantly lower power output and pace over the final fourteen percent of the time trial, a finding with implications for endurance events with increased effort near the finish line. Muscle glycogen content was not measured in this study but subjects consumed habitual diets of 58-60% of energy as carbohydrate to provide adequate, but not supercompensated, glycogen levels. The food journals collected prior to the first and third

trials indicated that subjects appeared to have complied with the recommendations to consume a moderate-high carbohydrate diet and limit exercise the day before all trials.

SUMMARY

The results of this study indicate pre-exercise meals with differing glycemic indices significantly alter substrate utilization throughout 60 minutes of submaximal (70% $VO_{2\ max}$) exercise. The fed trials resulted in significantly higher RER values ($p<.001$) and increased carbohydrate oxidation than in the control (fasted) trial. The highest RER was observed with the high GI trial (corn flakes, milk, banana), followed by the moderate GI trial (oatmeal, milk, banana) and then the fast. The high GI meal resulted in lower plasma glucose at the beginning of exercise than the fasted trial ($p=.018$) but there was no significant differences in glucose levels between the two fed trials. The fed trials produced no significant treatment effects on blood glucose and lactate throughout 60 minutes of submaximal exercise. Plasma FFA increased significantly ($p=.037$) from 0-15 minutes with the moderate GI meal while the high GI meal inhibited the rise. However, for the remainder of submaximal exercise, there were no significant differences between treatments upon FFA. During the maximal performance test to exhaustion immediately following the submaximal test, there were no significant treatment effects on plasma glucose, lactate or FFA. At the conclusion of the maximal test, there was no difference in RER with any treatment. There was no significant treatment effect on VO_2, VCO_2, V_E, heart rate during either the 60-minute submaximal trial or the maximal performance test to exhaustion. There was also no treatment effect on time to exhaustion or on work output at end of the performance test. In short, the moderate GI meal used in this experiment significantly altered substrate utilization during 60 minutes of submaximal exercise by increasing carbohydrate oxidation above the fasted trial but below the high GI trial. This

did not, however, help to significantly increase substrate availability during the exercise period or improve endurance performance.

REFERENCES

American College of Sports Medicine. (1991). Guidelines for Exercise Testing and Prescription. Philadelphia: Lea and Febiger.

Brouns, F., Rehrer, N.J., Saris, W.H.M., Beckers, E., Menheere, P. & ten Hoor, F. (1989) Effect of carbohydrate intake during warming-up on the regulation of blood glucose during exercise. International Journal of Sports Medicine, 10, S68-S75.

Burke, L.M., Collier, G.R. & Hargreaves, M. (1993). Muscle glycogen storage after prolonged exercise: effect of the glycemic index of carbohydrate feedings. Journal of Applied Physiology, 75, 1019-1023.

Chew, I., Brand, J.C. Thorburn, A.W. & Truswell, A.S. (1988). Application of glycemic index to mixed meals. American Journal of Clinical Nutrition, 47, 53-56.

Coleman, E. (1994) Update on carbohydrate: solid versus liquid. International Journal of Sport Nutrition, 4, 80-88.

Coggan, A.R. & Swanson, S.C. (1992) Nutritional manipulations before and during endurance exercise: effects on performance: effects on performance. Medicine and Science in Sports and Exercise, 24, S331-S335.

Coggan, A.R. (1991) Plasma glucose metabolism during exercise in humans. Sports Medicine, 11, 102-124.

Costill D.L. & Hargreaves, M. (1992) Carbohydrate nutrition and fatigue. Sports Medicine, 13, 86-92.

Costill, D.L., Coyle, E., Dalsky, G., Evans, W., Fink,W. & Hoopes, D. (1977) Effects of elevated ffa and insulin on muscle glycogen usage during exercise. Journal of Applied Physiology, 43, 695-699.

Coyle, E.F. & Coyle, E. (1993). Carbohydrates that speed recovery from training. Physician and Sportsmedicine, 21, 111-123.

Coyle, E.F., Coggan, A.R., Hemmert, M.K., Lowe, R.C. & Walters, T.J. (1985) Substrate usage during prolonged exercise following a pre-exercise meal. Journal of Applied Physiology, 59, 729-433.

Dunford, M. & Saunders, C. (1993) Postprandial glycemic response in three male endurance athletes. International Journal of Sport Nutrition, 3, 443-449.

Flynn, M.G., Michaud, T.J., Rodriguez-Zayas, J., Lambert, C.P., Boone, J.B. & Moleski, R.W. (1989) Effects of 4- and 8-hour pre-exercise feedings on substrate use and performance. Journal of Applied Physiology, 67, 2066-2071.

Foster, C., Costill, D.L. & Fink W.J. (1979) Effects of pre-exercise feedings on endurance performance. Medicine and Science in Sports and Exercise, 11, 1-5.

Hagerman, F.C. (1992) Energy metabolism and fuel utilization. Medicine and Science in Sports and Exercise, 24, S309-S314.

Hargreaves, M. & Briggs, C.A. (1988) Effect of carbohydrate ingestion on exercise metabolism. Journal of Applied Physiology, 65, 1553-1555.

Hargreaves, M, Costill, D.L., Katz, A. & Fink W.J. (1985) Effect of fructose ingestion on muscle glycogen usage during exercise. Medicine and Science in Sports and Exercise, 17, 360-363.

Hargreaves, M., Costill, D.L., Fink, W.J., King, D.S. and Fielding, R.A. (1987) Effect of pre-exercise carbohydrate feedings on endurance cycling performance. Medicine and Science in Sports and Exercise, 19, 33-36.

Harkins, C., Cary, R., Clark, N. & Bernadot, D. (1993) Protocols for dietary prescriptions. In Sports Nutrition: A Guide for the Professional Working with Active People. Bernadot, D. Ed., Chicago, IL: The American Dietetic Association, 178-182.

Hasson, S.M. & Barnes, W.S. (1989) Effect of carbohydrate ingestion on exercise of varying intensity and duration. Sports Medicine, 8, 327-334.

Horowitz, J.F. & Coyle, E.F. (1993) Metabolic response to pre-exercise meals containing various carbohydrates and fat. American Journal of Clinical Nutrition, 58, 235-241.

Hultman, E., Harris, R.C., & Spriet, L.L. (1994) Nutrition in Work and Exercise. In Modern Nutrition in Health and Disease. Shils, M.E., Olson, J.A., & Shike, M., Eds. Malvern, PA: Lea & Febiger, 663-678.

Jannson, E. & Kauser, L. (1982) Effect of diet on the utilization of blood-borne and intramuscular substrates during exercise in man. Acta Physiological Scandenavia, 115, 19-30.

Jenkins, D.J.A., Wolever, T.M.S., Taylor, R.H., Barker, H., Fielden, H., Baldwin, J.M., Bowling, A.C., Newman, H.C., Jenkins, A.L. & Goff, D.V. (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. American Journal of Clinical Nutrition, 34, 362-366.

Loomis, M. (1961). An enzymatic fluorometric method for the determination of lactic acid in serum. Journal of Laboratory and Clinical Medicine, 57, 966-969.

McArdle, W.D., Katch, F.I., & Katch, V.L. (1991) Exercise Physiology: Energy, Nutrition and Performance, Malvern, PA: Lea & Febiger, 76-78.

Muoio, D.M., Leddy, J.J., Horvath, P.J., Awad, A.B., & Pendergast, D.R. (1994) Effect of dietary fat on metabolic adjustments to maximal VO_2 and endurance. Medicine and Science in Sports and Exercise, 26, 81-88.

Neufer, R.D., Costill, D.L., Flynn, M.G., Kirwan, J.P., Mitchell, J.B. & Houmard, J. (1987) Improvements in exercise performance: effects of carbohydrate feedings and diet. Journal of Applied Physiology, 62, 983-988.

O'Brien, M.J., Viguie, C.A., Mazzeo, R.S. & Brooks, G.A. (1993). Carbohydrate dependence during marathon running. Medicine and Science in Sports and Exercise, 25, 1009-1017.

Paul, G.L., Layman, D.K., Boileau, R.A., Rokusek, J.T. & Dykstra, G.L. (1993) Unpublished poster session from the 1993 Annual meeting of the American Dietetic Association. Journal of the American Dietetic Association, 93, Supp A30.

Ritz, P., Krempf, M., Cloarec, D., Champ, M., & Charbonnel, B. (1991) Comparative continuous-indirect-calorimetry study of two carbohydrates with glycemic indices. American Journal of Clinical Nutrition, 54, 855-859.

Seifert, J.C., Paul, G.L., Eddy, D.E., & Murray, R (1994) Glycemic and insulinemic response to preexercise carbohydrate feedings. International Journal of Sports Nutrition, 4, 46-53.

Sherman, W.M., Doyle, J.A., Lamb, D.R., & Strauss, R.H. (1993) Dietary carbohydrate, muscle glycogen, and exercise performance during 7 days of training. American Journal of Clinical Nutrition, 57, 27-31.

Sherman, W.M., Peden, M.C., & Wright, D.A. (1991) Carbohydrate feedings 1 hour before exercise improves cycling performance. American Journal of Clinical Nutrition, 54, 860-870.

Shimuzu, S., Inoue, K., Tani, Y., & Yamada, H. (1979). Enzymatic microdetermination of serum free fatty acids. Analytical Biochemistry, 98, 341-345.

Thomas, D.E., Brotherhood, J.R. & Miller, J.B. (1994) Plasma glucose levels after prolonged strenuous exercise correlate inversely with glycemic response to food consumed before exercise. International Journal of Sport Nutrition, 4, 361-373.

Thomas, D.E., Brotherhood, J.R. & Brand, J.C. (1991). Carbohydrate feedings before exercise: effect of glycemic index. International Journal of Sports Medicine, 12, 180-186.

Wilbur, R.L., & Moffat, R.J. (1992) Influence of carbohydrate ingestion on blood glucose and performance in runners. International Journal of Sport Nutrition, 2, 317-327.

Widrick, J.J., Costill, D.L., Fink, W.J., Hickey, M.S., McConnell, G.K., & Tanaka, Hirofumi, H. (1993) Carbohydrate feedings and exercise performance: effect of initial glycogen concentration. Journal of Applied Physiology, 74, 2998-3005.

Wolever, T.M.S., Jenkins, D.J.A., & Josse, R.C. (1991). The glycemic index: methodology and clinical implications. American Journal of Clinical Nutrition, 54, 846-854.

APPENDICES

APPENDIX A

Human Research Project Approval Form

Colorado State University

Regulatory Committees
Office of V. P. for Research
Fort Collins, CO 80523
(303) 491-6355
FAX (303) 491-6147

MEMORANDUM

TO Mary Harris
Department of Food Science & Human Nutrition

FROM: LaVina Matzdorff, Administrator
Human Research Committee

SUBJECT: PROJECT APPROVAL
Title: The Effects of Differing Glycemic Index Meals on Substrate Utilization and Endurance Performance
Protocol No.: 94-104H
Funding Agency: College of Applied Human Sciences
Funding Agency Deadline: N/A

DATE: June 27, 1994

The above-referenced project was approved by the Human Research Committee on June 23, 1994 for the period June 23, 1994 to June 23, 1995 with the condition that the attached consent form is signed by each subject and each subject is given a copy of the form. It is the investigator's responsibility to obtain this consent form from all subjects. NO changes may be made to this document without first obtaining the approval of the Committee.

A status report of this project will be required within a 12-month period from the date of approval. The necessary form (H-101) will be mailed to you prior to that date.

It is the responsiblity of the investigator to immediately inform the Committee of any serious complications, unexpected risks or injuries resulting from this research.

It is also the investigator's responsibility to notify the Committee of any changes in experimental design or consent procedures (file Form H-101).

Any questions about the Committee's action on this project should be directed to me.

Attachment
xc: S. Black

APPENDIX B

Subject Informed Consent Form

COLORADO STATE UNIVERSITY
INFORMED CONSENT TO PARTICIPATE IN A RESEARCH PROJECT

TITLE OF PROJECT: The effects of differing glycemic index meals on substrate utilization and endurance performance.

NAME OF PRINCIPAL INVESTIGATOR: Mary Harris, Ph.D.

NAME OF CO-INVESTIGATOR: Steve Black

CONTACT NAME AND PHONE NUMBER FOR QUESTIONS/PROBLEMS: Steve Black , 221-0412

SPONSOR OF PROJECT: College of Applied Human Sciences

PURPOSE OF THE RESEARCH: The purpose of this study is to measure the effects of different meals on athletic endurance performance and on substrate use of blood fats and sugars.

PROCEDURES/METHODS TO BE USED:
1. Maximal and submaximal bicycle tests: Will provide measures of cardiovascular endurance. Subjects will perform 4 trials on the bicycle: one maximal test followed by three tests which combine a 75 minute submaximal ride with a maximal test at the end of 75 minutes. The maximal test will involve a gradual increase in workload until the subject can no longer continue or wishes to stop. During the test, subjects will be equipped with a nose clip and inhale room air through a 3-way valve into a metabolic cart. A cm-5 lead ECG test will be administered to monitor the heart rate during all trials. The submaximal test will involve 75 minutes of pedaling at a given workload and then a maximal test will performed until exhaustion or until the subject chooses to stop.

2. Blood Sampling: Blood will be drawn at 15-minute intervals throughout the test as well as before eating and before exercise.

3. Meals: Before each of the 3 submaximal/maximal trials, subjects will consume a meal of typical breakfast foods or fast.

RISKS INHERENT IN THE PROCEDURES:

1. Maximal Exercise Testing: Fatigue, muscle strains, heart abnormalities (arrhythmia's), 0.01% chance of death (in cardiac population), 0.02% risk of cardiac arrhythmia's requiring hospitalization (in a cardiac population), and change of blood pressure.

2. Submaximal Exercise (up to 80% VO_2 Max.): Fatigue, boredom (if prolonged length of time), muscle soreness

3. Blood Draw/Cannulation: hematoma (bruise), slight risk of infection, local soreness, fainting

I understand that it is not possible to identify all potential risks in an experimental procedure, but I believe that reasonable safeguards have been taken to minimize both the known and the potential, but unknown, risks.

BENEFITS: General benefits of the study include making pre-exercise recommendations on food selection to athletes. The results of the study will provide a measure of the subject's maximal oxygen consumption, which is indicative of aerobic capacity. Results from maximal exercise test can then be used for developing an exercise program or exercise prescription. Nutritional analysis will provide the subject with detailed information about their normal eating habits and provide tips for improving nutrient intake.

ASSURANCE OF CONFIDENTIALITY: Strict confidentiality will be maintained by assignment of code numbers. No subject will be referred to by name in any written or oral communication.

 Subject's Initials ____ Date ____

LIMITATION OF LIABILITY:

Because Colorado State University is a publicly-funded, state institution, it may have only limited legal responsibility for injuries incurred as a result of participation in this study under a Colorado law known as the Colorado Governmental Immunity Act (Colorado Revised Statutes, Section 24-10-101, et seq.). In addition, under Colorado law, you must file any claim against the University within 180 days after the date of the injury.

In light of these laws, you are encouraged to evaluate your own health and disability insurance to determine whether you are covered for any injuries you might sustain by participating in this research, since it may be necessary for you to rely on your individual coverage for any such injuries. If you sustain injuries which you believe were caused by Colorado State University or its employees, we advise you to consult an attorney.

Questions concerning treatment of subjects' rights may be directed to LaVina Matzdorff at 303-491-6355.

PARTICIPATION:

I understand that my participation in this research is voluntary. If I decide to participate in the study, I may withdraw my consent and stop participating at any time without penalty or loss of benefits to which I am otherwise entitled.

I have read and understand the information stated and willingly sign this consent form. My signature also acknowledges that I have received, on the date signed, a copy of this document containing 2 pages.

_____
Subject name (printed)

_____ _____
Subject signature Date

_____ _____
Investigator or co-investigator signature Date

APPENDIX C

Medical Questionnaire

MEDICAL QUESTIONNAIRE

Name: _____ **Gender:** M F **Date of Birth**: _____
Address: _____
Phone: Home _____ Work: _____ **Height:** _____ **Weight:** _____

1. Do you have any food allergies or intolerances? Please describe: _____
_____

2. Have you ever been diagnosed as having any of the following and if yes, how are you currently treating the condition?
   - Y N High Blood Pressure _____
   - Y N High Cholesterol or High Triglycerides _____
   - Y N Diabetes _____
   - Y N Hypoglycemia _____
   - Y N Asthma _____

3. Does anyone in your family (immediate family including your grandparents) have a history of cardiovascular disease? (heart attacks, strokes, etc.) Please explain: _____
_____

4. Are you currently taking any medication including over-the-counter drugs? Please list: _____
_____

5. Do you smoke? _____

6. Do you have any neurological problems including fainting, dizziness, headaches or seizures? If yes, please explain. _____

7. Do you have any orthopedic or other health problems which may affect your ability to perform a maximal exercise test? If yes, please explain. _____
_____

8. Have you ever had a glucose tolerance test? Y N
If yes, what were the results? _____

9. Have you ever had a fasting blood sugar test? Y N
If yes, what were the results? _____

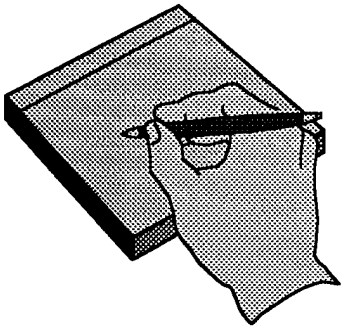
10. Do you exercise regularly? _____ How often? _____
What type of exercise? _____

11. Have you had a physical exam in the past two years? Y N Are you in good health? Y N

Participant's Signature: _____ **Date:** _____
Investigator's Signature: _____ **Date:** _____

APPENDIX D

Food Journal



Food Journal

1. The food journal will provide necessary information about your eating habits - it is an important part of the study - please be as complete and accurate as possible! Record all food and drink consumed for the 3 days before your test. I need you to note how much and what kind of food and also how it was cooked. Be specific - not just "milk and cereal" but "2 cups Cap'n Crunch, 1/2 banana, 3 quarts 2% skim milk, 1/4 cup sugar, etc."

Another Example:

Amount	Food
6 ounces	Chicken breast, fried
2 Tablespoons	Frozen green beans, steamed
2 small ears	Fresh Corn
2 1/2 cups	Iced Tea w/ 1 teaspoon sugar
1 small	Raw Apple
2 slices	Bread (WW)
2 12 oz bottles	Beer (Coor's Light)

2. To approximate serving sizes: (also see attached sheets)
   1 ounce of meat = thin slice of meat about the diameter of a piece of bologna
   1 chicken breast = 3 1/2 ounces; 1 chicken leg = 2 ounces
   1 coffee cup = 6 ounces; 1 coffee mug = 12 ounces

3. If the food contains a combination of ingredients (such as pizza or a casserole), explain it in as much detail as possible:

   1 slice of pizza (1/6 of a 14 inch large Pizza Hut pizza) with cheese, pepperoni and onions.

4. Don't forget snacks, drinks or anything else! Please record all food which goes into your mouth! Yes, even gum. Remember to put down whether anything is "regular" or "sugar free."

5. Remember to write down condiments such as ketchup, mustard, mayonnaise, jam or jelly.

6. If fruit is canned, be sure to note whether it was canned in water, fruit juice or syrup.

7. Do your best and we'll go over it when you come back in.

8. I also need you to keep track of your exercise during those three days. Please note the type, length and intensity of any activity.

Checklist for Food Journals

Use this checklist to help keep an accurate food journal. Compare each item in your journal to the appropriate type of food. Include enough details in your description to answer the questions below.

Type of Food	Did You Specify.....
All	☑ Amount eaten? By cup, tablespoon, or teaspoon? By size, giving dimensions: length, width, thickness or diameter? By number? By Weight?
Cereals	☑ Size of servings? Brand name? Additions such as milk, sugar, fruit, nuts? Instant or ready-to-eat type?
Baked Goods	☑ Homemade or commercial? From scratch or mix? Brand? Topping or frosting? Dimensions? Weight or number eaten?
Fruits & Juices	☑ Cooked, raw or dried? Peeled? Fresh, frozen or canned juice? Sweetened? Size of serving?
Vegetables	☑ Cooked or raw? Fresh, frozen or canned? Sauces or other additions? Serving size?
Milk Products	☑ Percent fat? Imitation or reduced calorie? Powder or liquid?
Meat, Fish, Poultry	☑ Type of cut? Percent fat? Oil or water packed? Fat, skin removed? How prepared? Additions? Cooked weight? Dimensions of amount eaten?
Eggs	☑ Size? How prepared? Added fat?
Mixed Dishes	☑ Homemade or commercial? From scratch or mix? Brand? Major ingredients and proportions? Cooking method?
Soups	☑ Homemade or commercial? Brand? Broth or milk-based? Type of milk? Principle ingredients?
Fats and Oils	☑ Stick, tub, diet, whipped, squeeze or liquid margarine? Brand? Major oil, brand of oil, and type of shortening? Homemade or commercial salad dressing? Type of oil or brand? Low calorie? Creamy? Additions?
Beverages	☑ Brand? Sweetened? Diet? Decaffeinated? Alcohol content? Additions? Amount?
Snacks	☑ Brand? Size, weight or number eaten?
Restaurant Meals	☑ Type: fast food, ethic, deli, family style?